Pedagogical labs utilizing a lock in amplifier

PSD via Lock-in = VERSATILITY & SIMPLICITY

Bill Brandon
Fuzzycist
UNCP

What is a lock-in amplifier?

- AC voltmeter (a darn good one!)
- Spectrum analyzer
- Phase meter
- Noise measurement
- Vector voltmeter

How does a lock in amplifier work?

The next few slides are a very simple description outlying a few of the most salient features.

How does a lock in amplifier work?

- Must be properly referenced
- Reference is phase shifted (user controlled or better yet use a dual phase lock-in)
- Signal (and noise) is amplified– although a bandpass filter can be used to eliminate some of the noise
- **PSD** (mixer) – the HEART of the lock in uses linear circuitry to multiply reference and signal of interest
- Low pass (RC) filter attenuates away noise

SRS 830: our best digital (new)

Digital unit, Dual phase … highly recommended

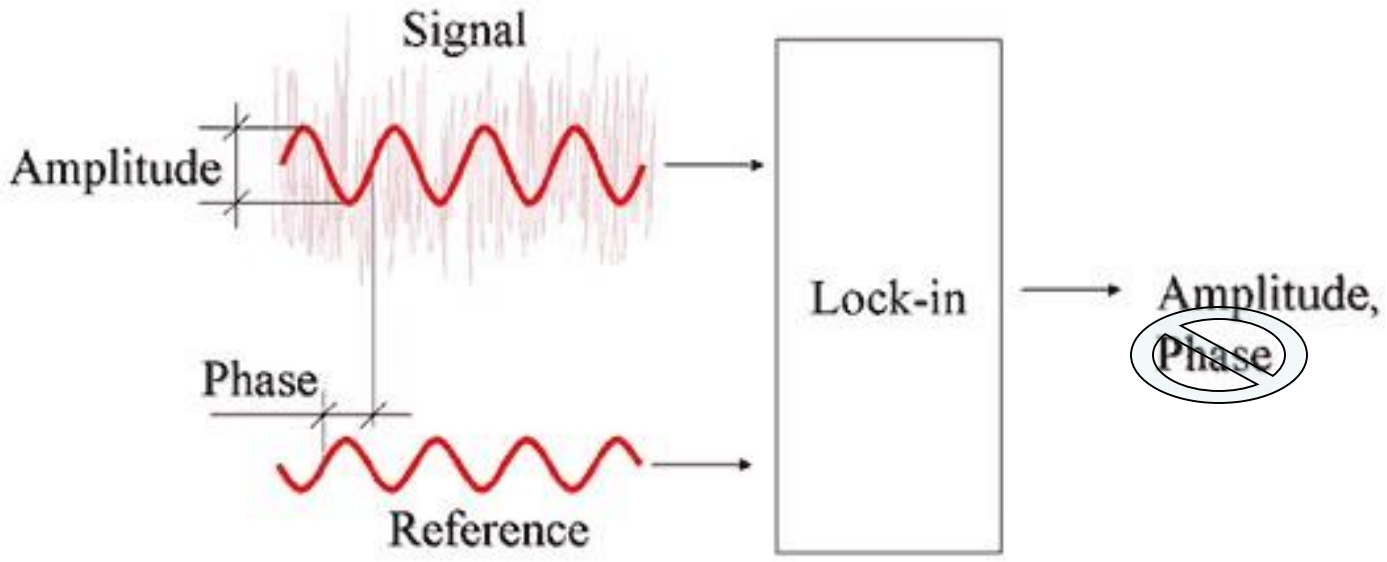
Ithaco 3921

ebay special at $49.99 and still working!

A single phase lock in

– can force the student to manually adjust phase

Black-box description (appropriate for intro physics labs)



http://zone.ni.com/cms/images/devzone/tut/2006-12-08_112403.jpg

Similar to triggering a scope – except -- you “REFERENCE” a lock in

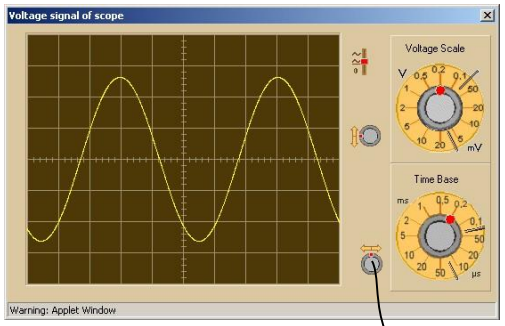
An appropriate experiment for this "Black Box" approach

- This Lab Activity introduces first year students to a lock-in amplifier

"Resonance and the Speed of Sound"

(with extreme noise)

Resonance and the speed of sound



Scope

speaker

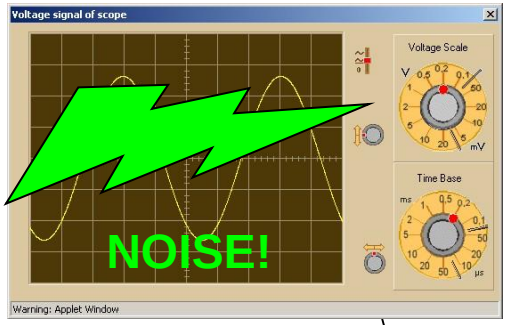
plunger

microphone

Function generator

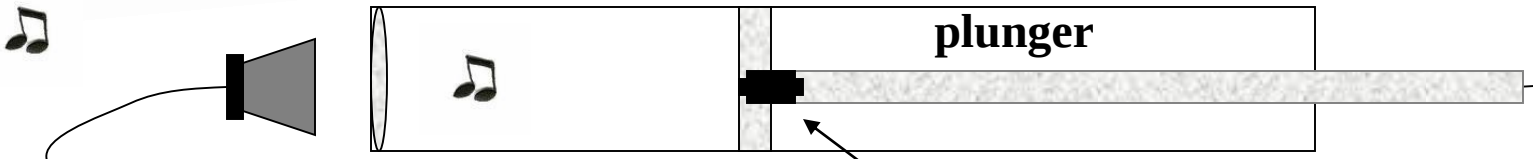
Simple enough!

Resonance and the speed of sound

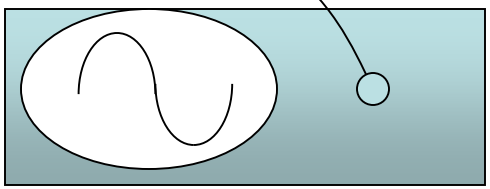


Scope

No chance! … is it Friday yet?



microphone



Function generator

Cannot pickup the constant tone amongst the rubbish

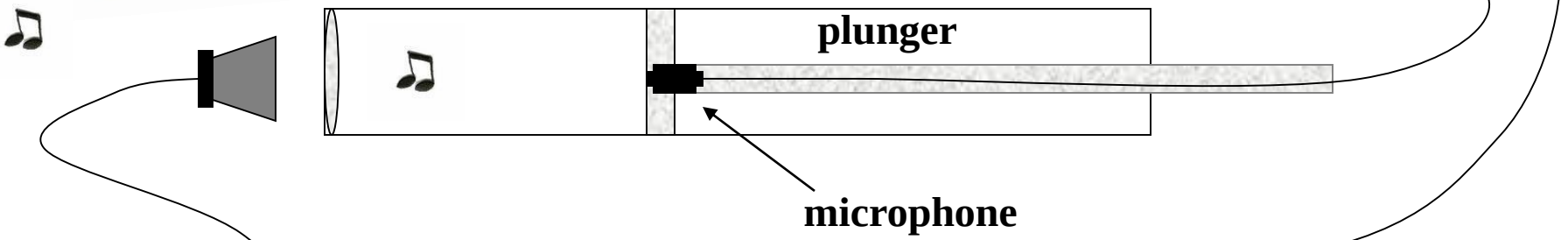
Resonance and the speed of sound

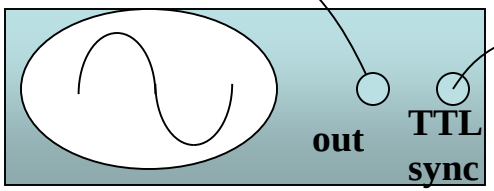
Lock in amplifier

signal

reference

No problem!





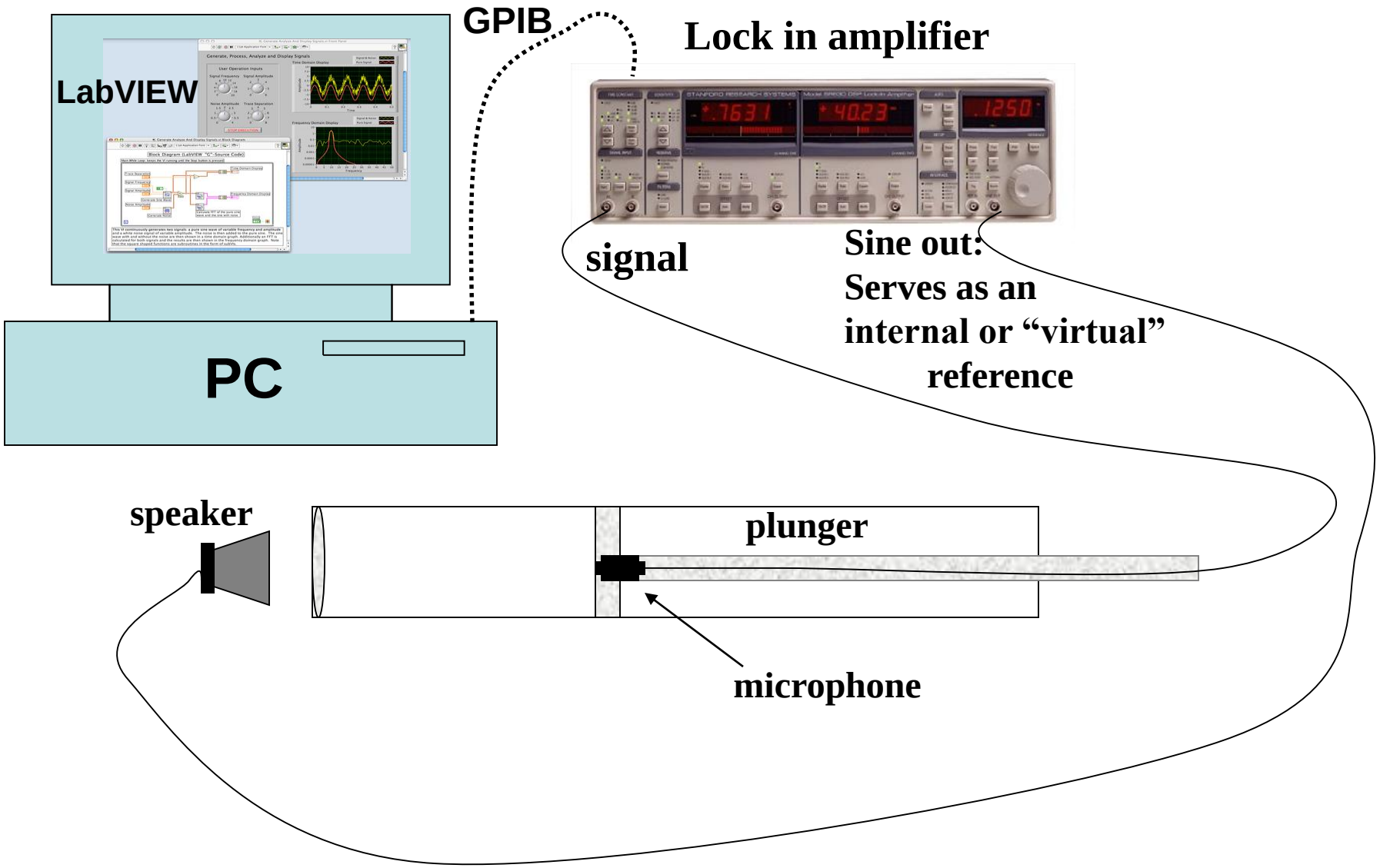
Function generator

In fact---better data than that obained from the scope and no noise!

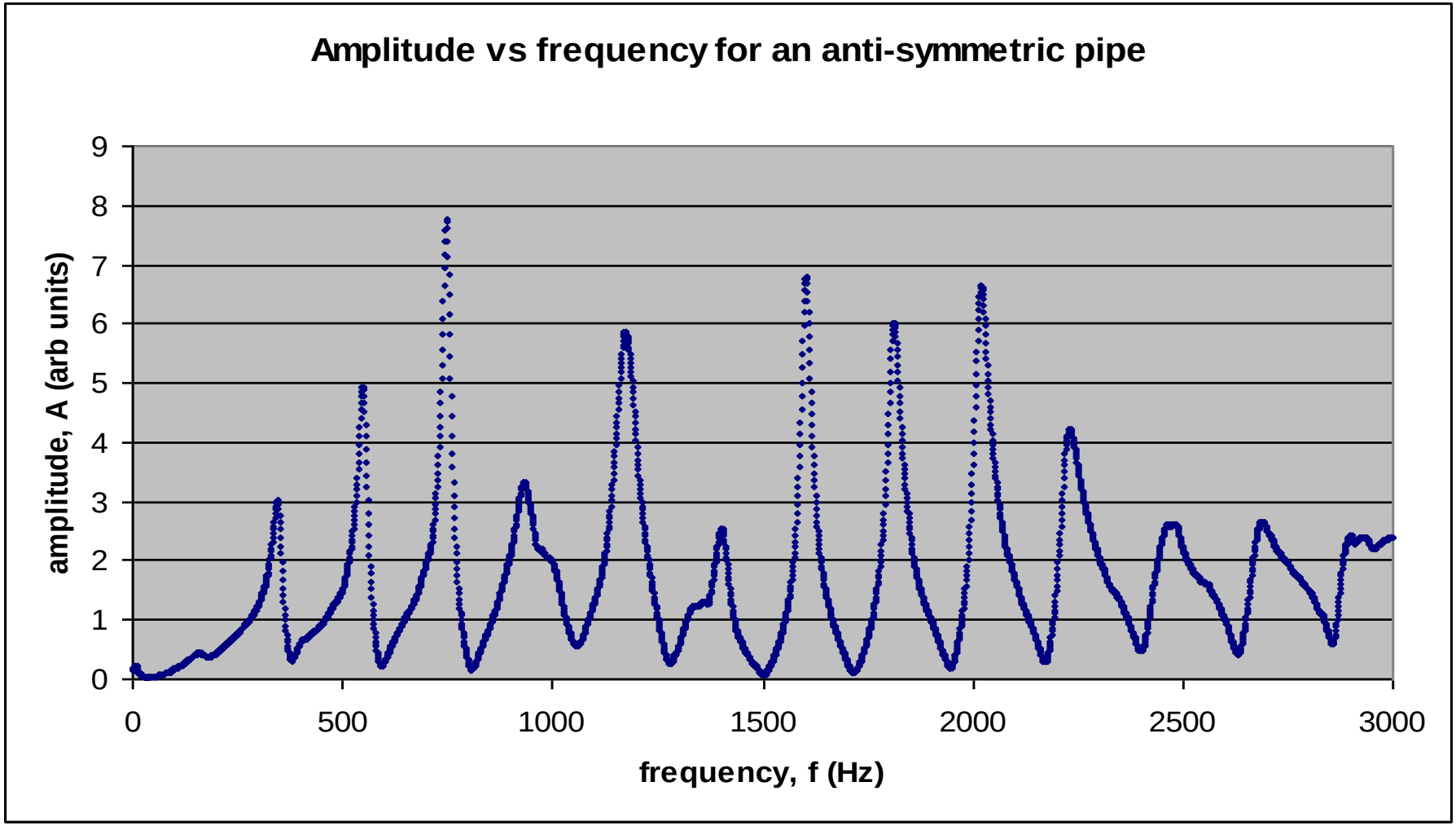
Intermediate Level labs

- Require some automated LabVIEW vi’s
- Still.. Very little about the lock-in

Improved Experiment: Automated with LabVIEW & GPIB

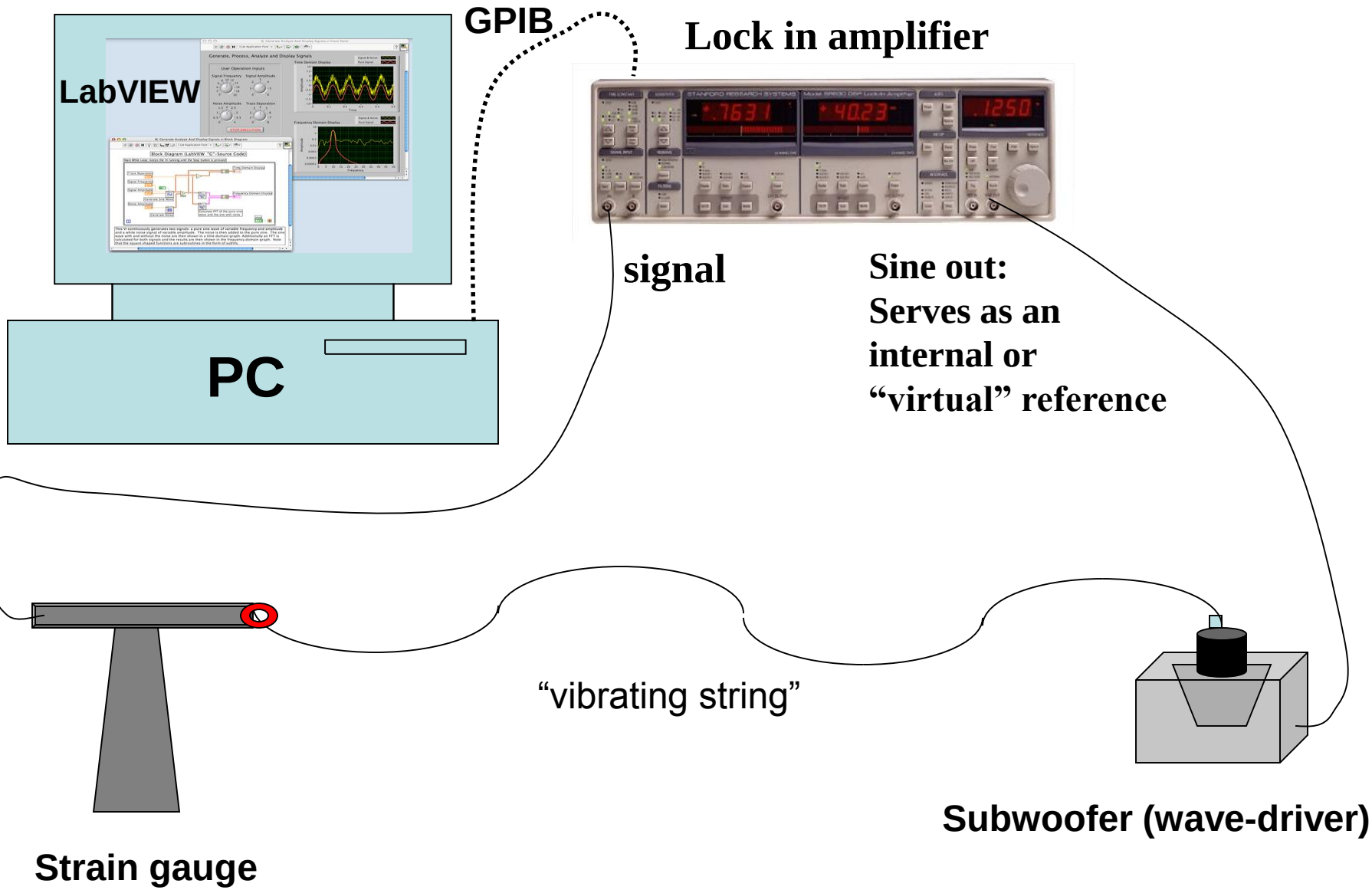


Amplitude vs. Frequency at fixed length for antisymmetric tube (80 cm)

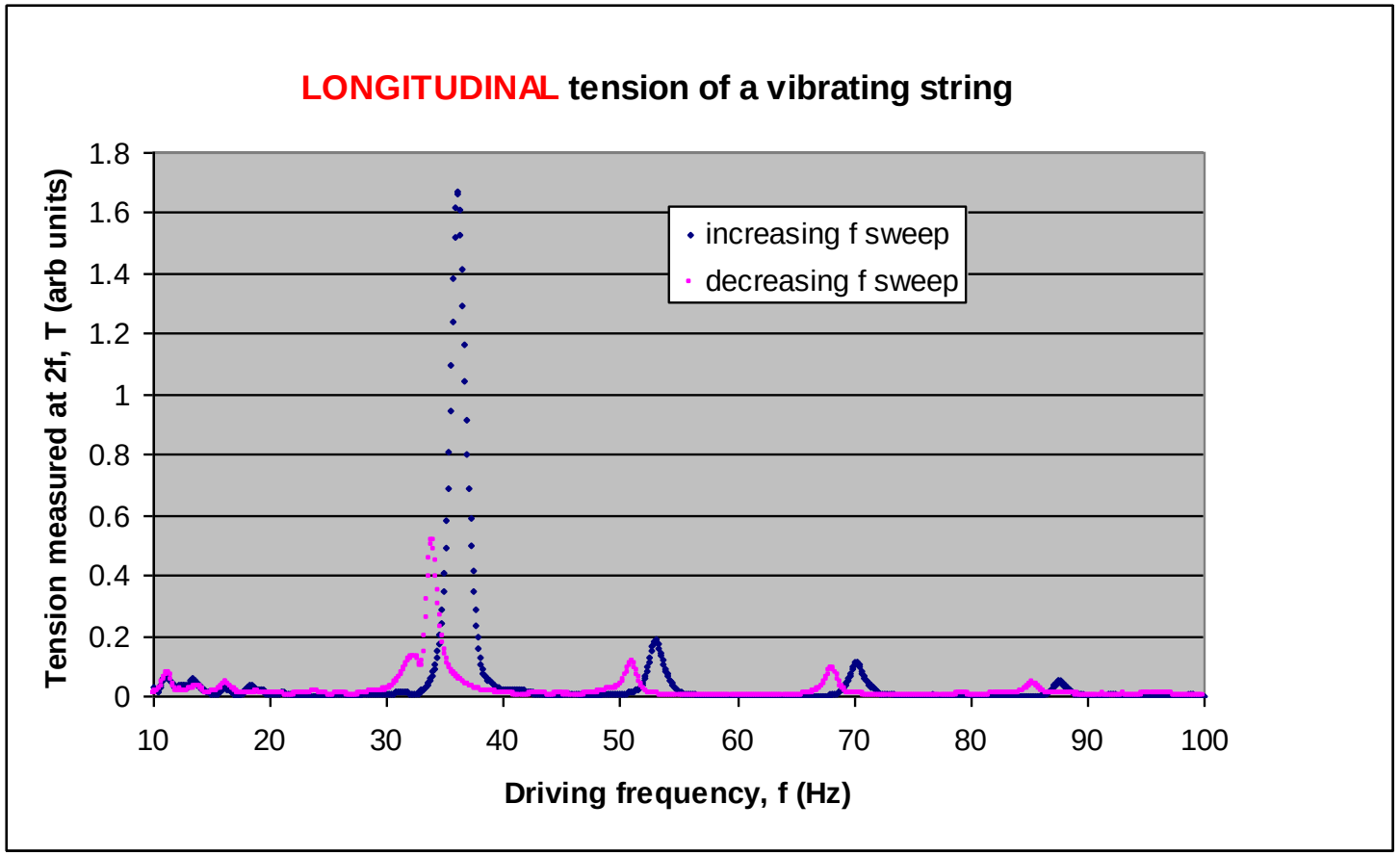


This scan was acquired in about 4 minutes

Variation on the “same theme”

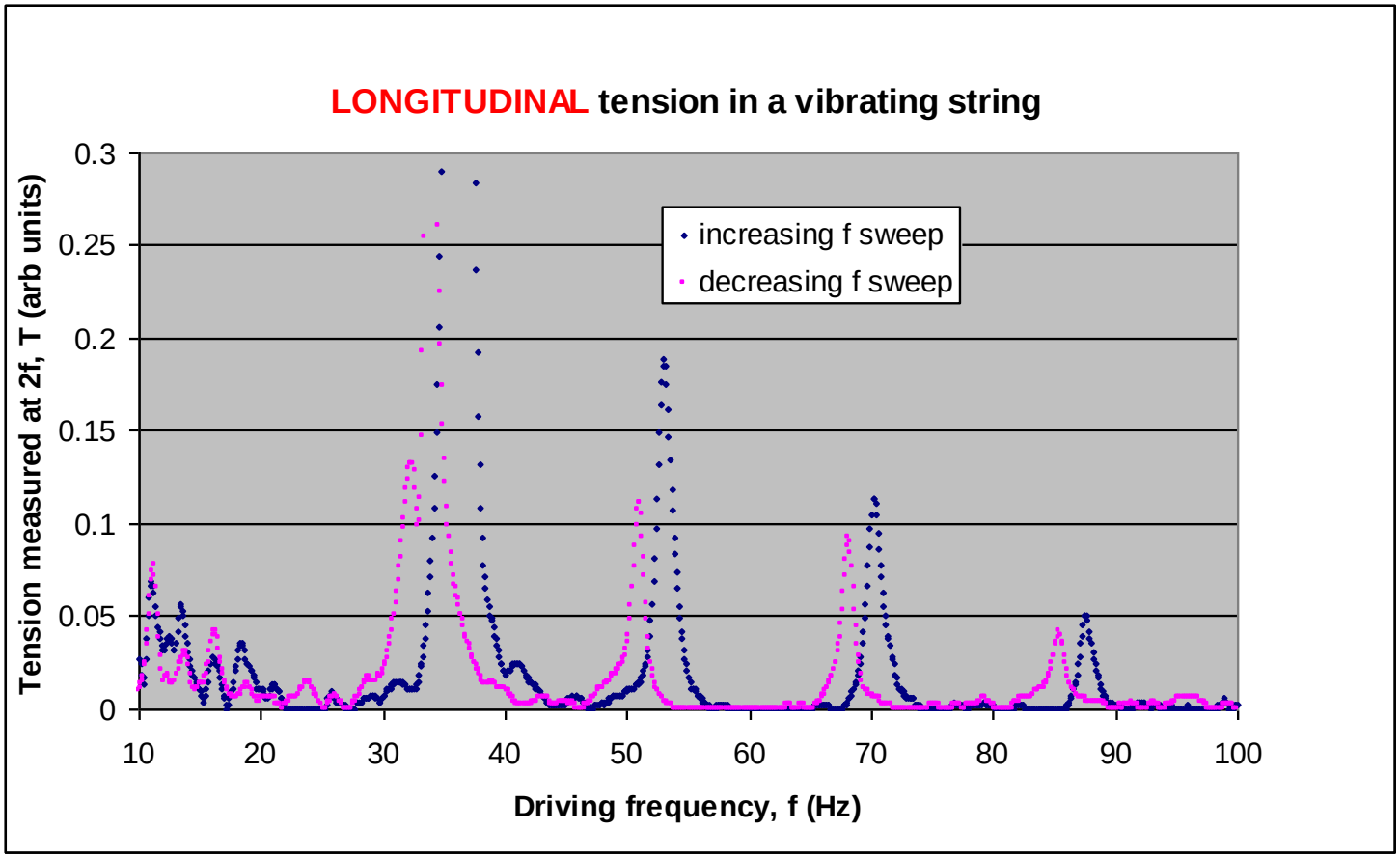


Frequency spectrum of the tension in a vibrating string



Spectrum acquired in 100 seconds

Frequency spectrum of the tension in a vibrating string (rescaled)



Perhaps the students become a little more interested in lock-in functionality??

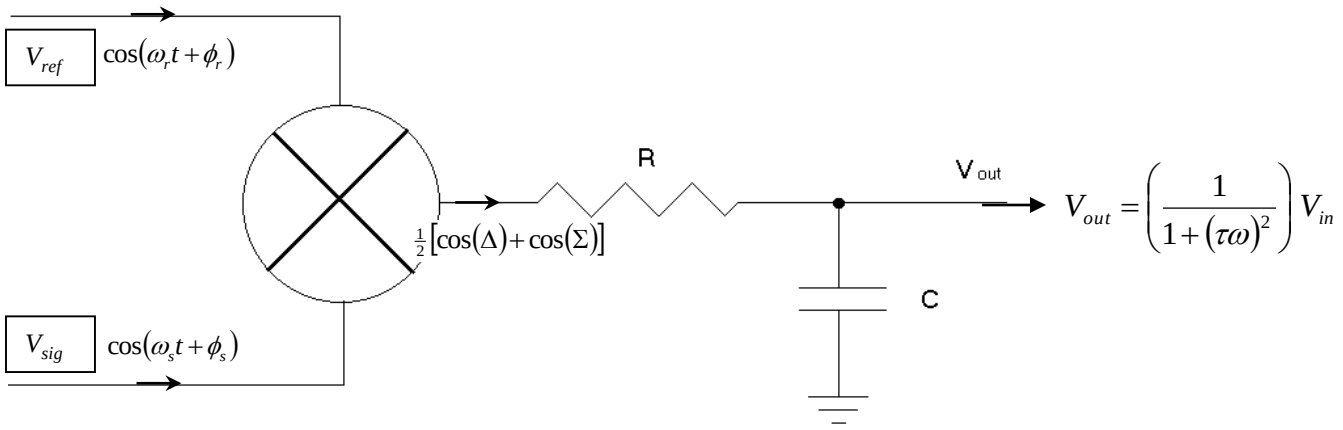
- As far as the GUI programming goes…most students do tend to make progress with LabVIEW rather quickly… a sort of positive reinforcement loop… not unlike video game addiction…etc

- …instruction without instruction…

Advance undergraduate lab activities

- More labVIEW
- Must understand basic lock-in functionality

PSD: the heart of the lock in amplifier



$$\cos(\omega_r t + \phi_r)\cos(\omega_s t + \phi_s) = \tfrac{1}{2}\left[\cos(\Delta)+\cos(\Sigma)\right]$$

$$\Delta = \left[(\omega_r - \omega_s)t + (\phi_r - \phi_s)\right] \quad and \quad \Sigma = \left[(\omega_r + \omega_s)t + (\phi_r + \phi_s)\right]$$

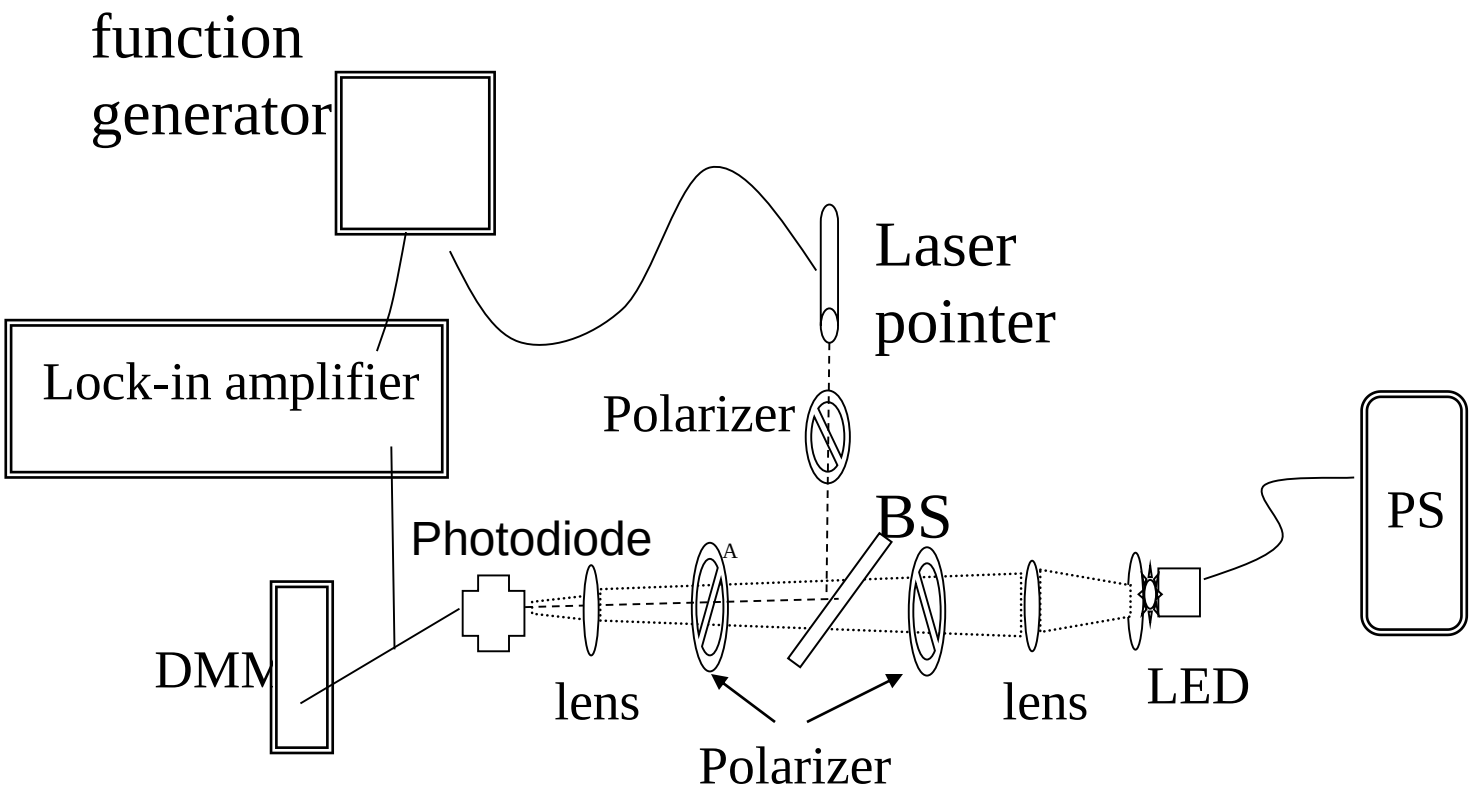
$$V_{out} = \left(\frac{1}{1+(\tau\omega)^2}\right) V_{in}$$

2 more experiments

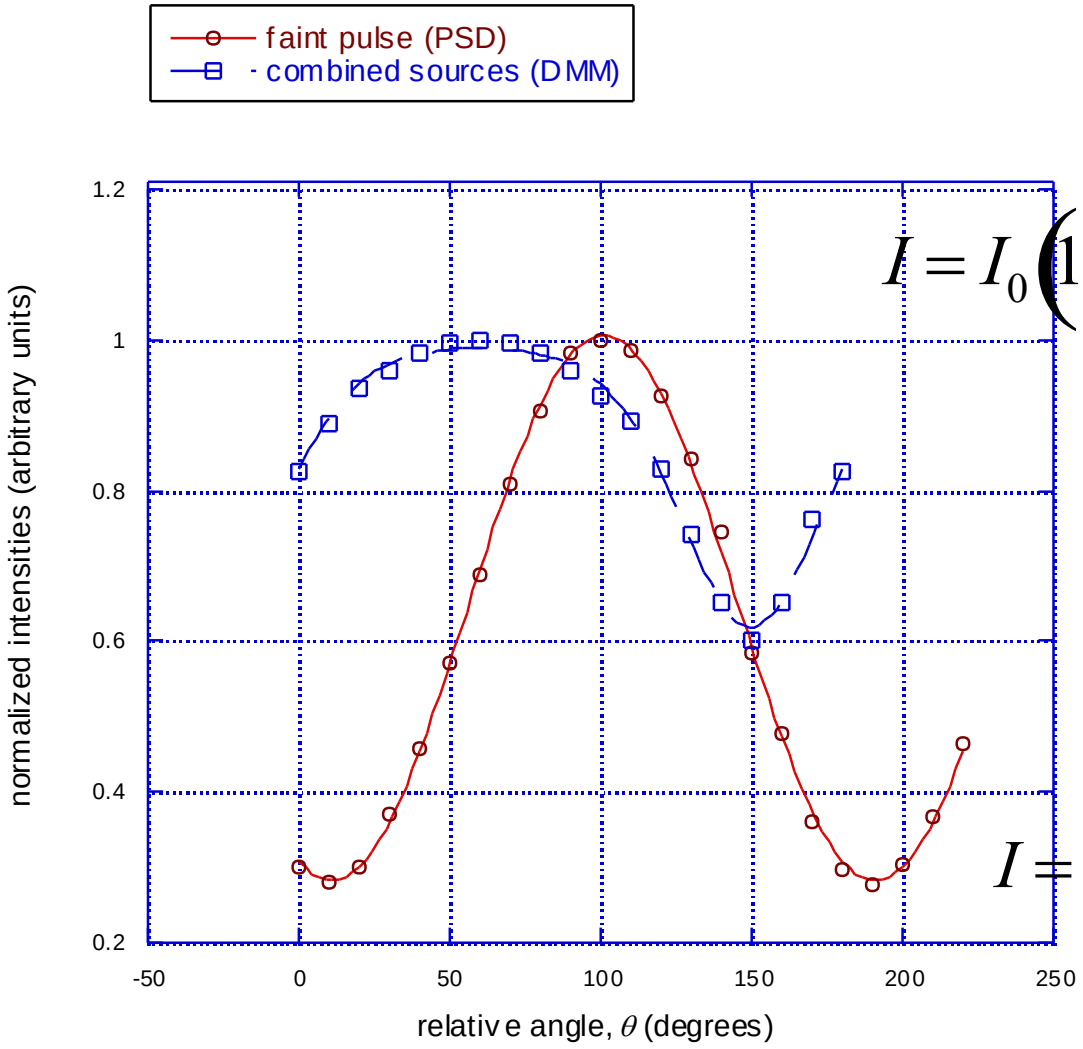
- Malus law with a noise so overwhelming that the photodiode is actually operating in a “saturated regime”

- The world’s simplest Faraday rotation apparatus

Malus Fit with a saturated PD



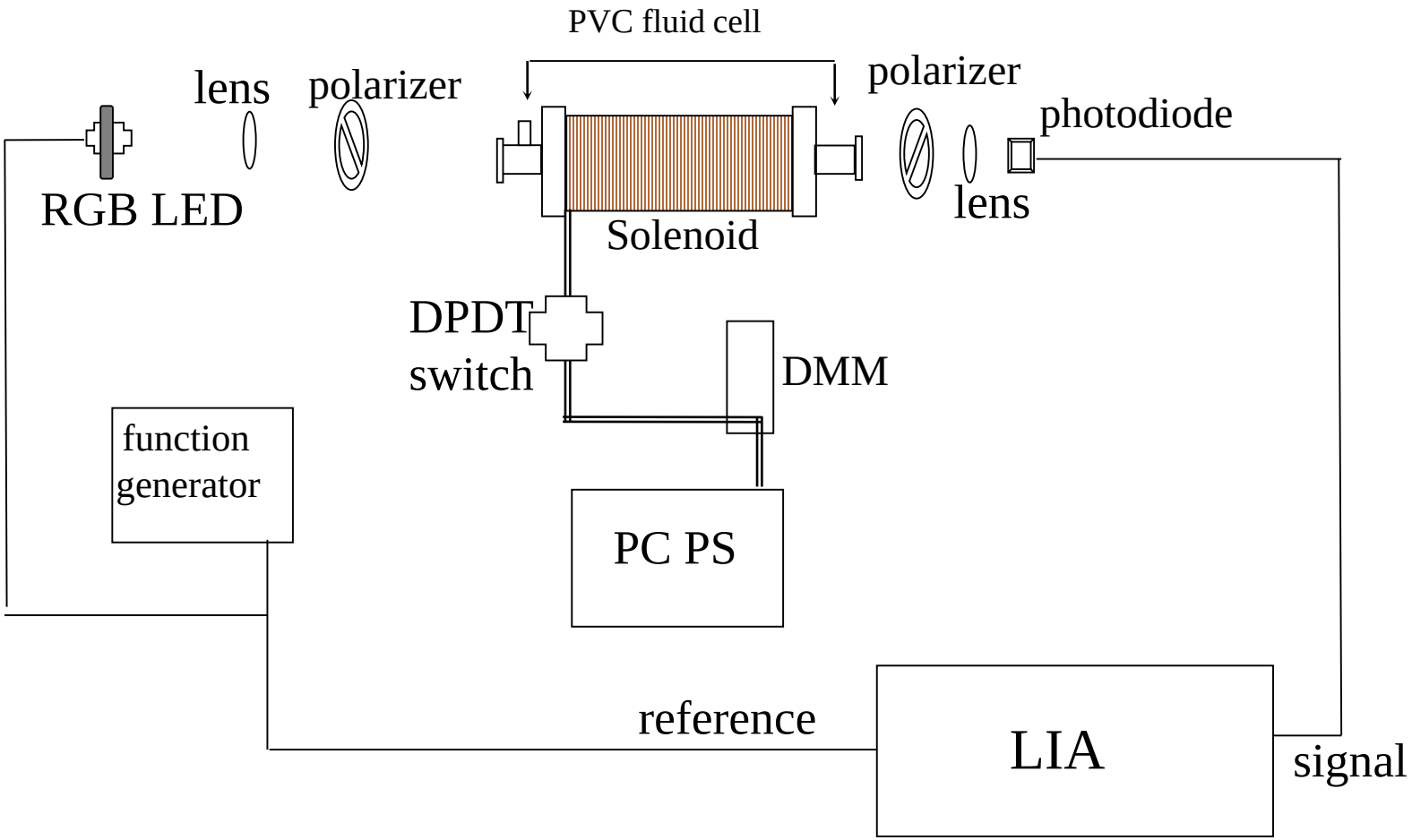
Malus Fit with a saturated PD



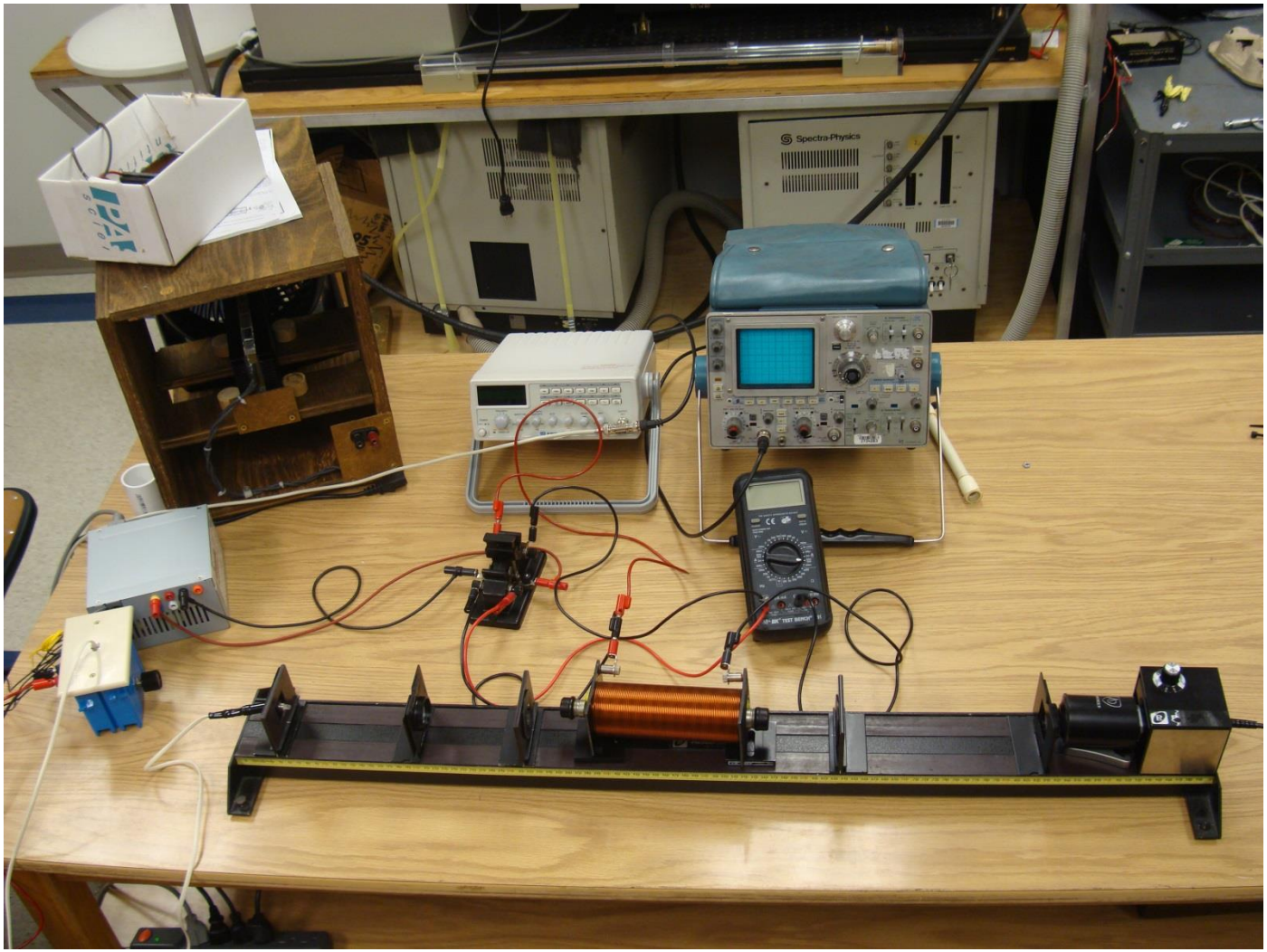
$$I = I_0\left(1 - e^{-\eta \cos^2(\theta - \theta_0)}\right) + I_{DC}$$

$$I = I_0 \cos^2(\theta - \theta_0) + I_{DC}$$

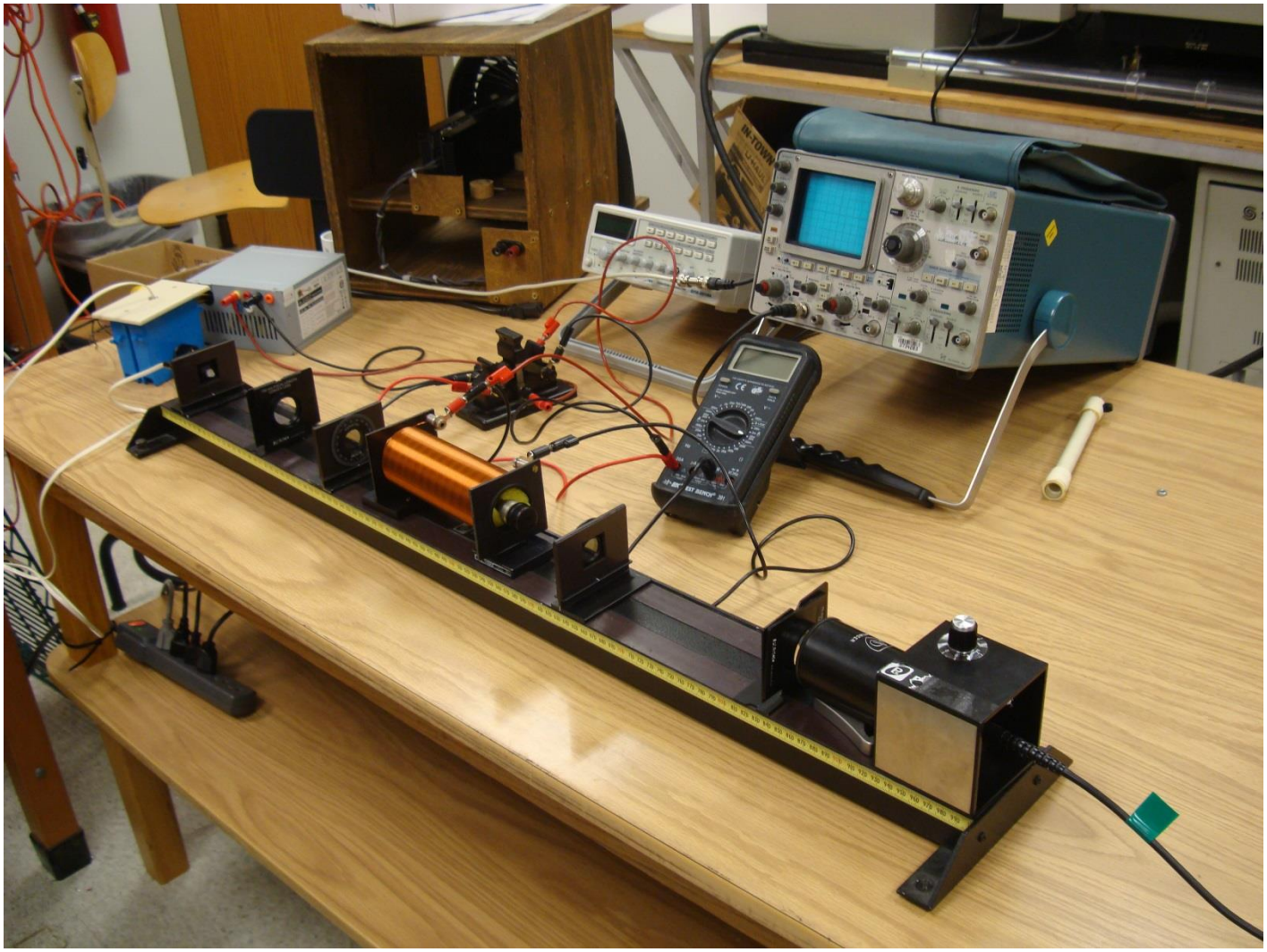
“Simplest” Faraday Rotation



The actual apparatus
(lock-in is on the other side of the room)



The actual apparatus
(lock-in is on the other side of the room)



Super Brief Theory

- "it can be shown"

$$V = \frac{1}{2}\sin^{-1}\left(\frac{\xi_- - \xi_+}{2V_0}\right) \approx \frac{\xi_- - \xi_+}{4V_0}$$

…and using solid methodology… consisting of NORMALIZATION used in calibration procedure

$I_+ \equiv V_+$ photodiode voltage (obtained with corresponding + solenoid current, i_+)

$I_- \equiv V_-$ photodiode voltage (obtained with corresponding - solenoid current, i_-)

$I_{45^0} \equiv V_0$ photodiode voltage (no solenoid current)

$\eta_+ = (Bl)_{eff} = mi_+ + b \rightarrow$

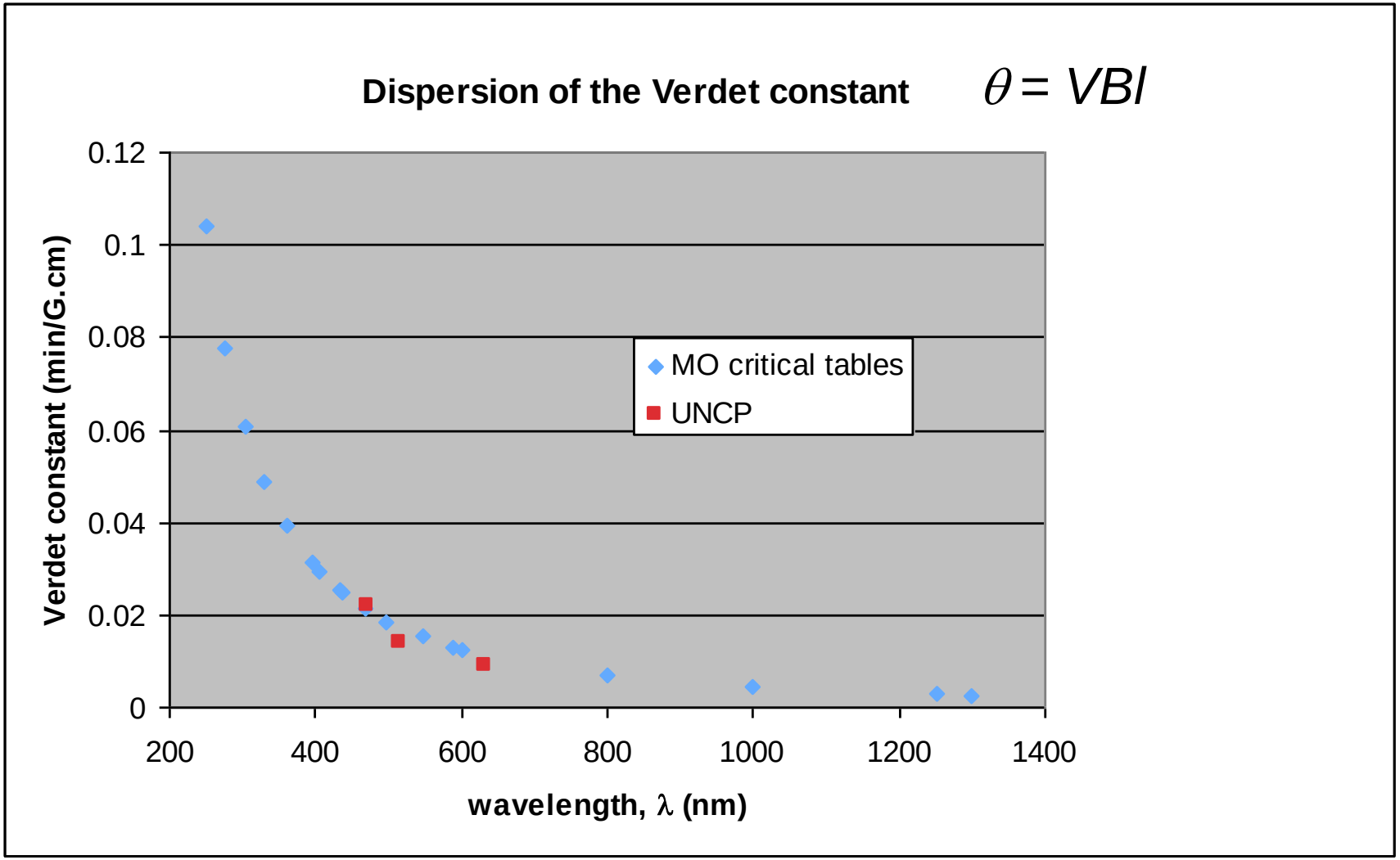
m,b fitting parameters from the solenoid characterization obtained simultaneoulsy with V_+

$\eta_- = (Bl)_{eff} = mi_- + b \rightarrow$

m,b fitting parameters from the solenoid characterization obtained simultaneoulsy with V_-

and finally : $\xi_+ \equiv V_+/\eta_+$ and $\xi_- \equiv V_-/\eta_-$

Faraday Rotation



Only 3 things you need to know

- When buying real estate

LOCATION

LOCATION

LOCATION

- When engineering experimental apparatus

METHODOLOGY

METHODOLOGY

METHODOLOGY

Acknowledgements

- Chris Concepcion (Jack of all trades)
- Matt Hoover (hardware extraordinaire)
- Stephanie Burr (The String)
- Stuart Hanmer (Mr. LabVIEW)